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EVALUATION OF ENGINE, HYDRAULIC, POWER TRANSMISSION, AND FINAL DRIVE LUBRICANTS FOR USE IN ARMY COMBAT/TACTICAL TRANSMISSIONS

INTERIM REPORT
BFLRF No. 271

By

H.W. Marbach, Jr.
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

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The objective of this program was to investigate commercial/proprietary hydraulic/power transmission fluids to establish criteria for supporting the use of military specification products in satisfying manufacturer warranty requirements and fully meeting equipment lubrication needs. The effort included the evaluation of selected candidate fluids through chemical/physical analyses and in transmission performance tests as defined in proprietary commercial fluid specifications.

Twenty lubricants were selected from a wide variety of commercial/proprietary/military engine, power transmission, hydraulic and final drive lubricants and evaluated with selected chemical/physical and bench tests. From these data, three lubricants underwent performance evaluation. The results of this work show that the military lubricants will meet the manufacturer warranty requirements with only a few upgrade

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19. ABSTRACT

modifications and that an OEA-30 engine, hydraulic, power transmission, and final drive lubricant could be developed, thereby allowing the continued multipurpose use of MIL-L-2104 lubricants in Army combat/tactical ground equipment.

The development of an OEA-30 lubricant for the MIL-L-2104 lubricant specification will remove two lubricant grades and eliminate the MIL-L-46167 specification from the Qualified Products List.

EXECUTIVE SUMMARY

<u>Problems and Objectives</u>: Developments in engine technology leading to higher engine temperatures and increased thermal-oxidative stress on engine oils, along with new emission requirements in 1991 and 1994 have resulted in formulation changes in engine lubricants. These changes may make the lubricants less desirable as power transmission/hydraulic/final drive fluids. As a result, several manufacturers of commercial construction equipment no longer permit the use of engine lubricants in their transmission/hydraulic/final drive systems, and void the warranty if engine lubricants are used. One objective of this program was to evaluate commercial/proprietary/military engine, hydraulic, power transmission, and final drive lubricants to obtain data to support military product usage and to satisfy manufacturers' warranty requirements. Other objectives were to determine the suitability of these products in current military equipment and to reduce the logistical burden in supplying additional fluids to the field.

<u>Importance of Project</u>: Tactical engine lubricants conforming to military specifications MIL-L-2104, MIL-L-21260, and MIL-L-46167 are used in the engine, hydraulic, transmission, and final drive systems of combat/tactical ground equipment. This long-standing practice was introduced to reduce the logistical burden in supplying additional fluids to the field and to preclude the potentially disastrous accident of adding transmission/hydraulic/final drive fluid to the engine.

<u>Technical Approach</u>: The approach was to select a wide variety of commercial/proprietary/military engine, power transmission, hydraulic, and final drive lubricants and evaluate them with selected chemical/physical and bench tests. From these data, three lubricants underwent performance evaluation. These data were then used to determine the possibility of developing a new OEA-30 engine, hydraulic, power transmission, and final drive lubricant for combat/tactical ground equipment using MIL-L-2104 and MIL-L-46167 lubricants.

<u>Accomplishments</u>: All selected lubricants were evaluated. The results of these evaluations show that the military specification lubricants will meet the manufacturer warranty requirements with only a few upgrade modifications and that an OEA-30 engine, hydraulic, power transmission, and final drive lubricant could be developed, thereby allowing the continued multipurpose use of MIL-L-2104 lubricants for engine, hydraulic, power transmission, and final drives. Also, a continued good rapport was maintained with the equipment and lubricant manufacturers.

<u>Military Impact</u>: The development of an OEA-30 lubricant for the MIL-L-2104 lubricant specification will remove two lubricant grades and eliminate the MIL-L-46167 specification. This result is in compliance with Army regulations to have multiple usage and keep lubricants at an absolute minimum for combat/tactical equipment.

FOREWORD

This work was performed at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute, San Antonio, TX, under Contract Nos. DAAK70-87-C-0043 and DAAK70-92-C-0059, for the period November 1988 through September 1991. Work was funded by the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center), Ft. Belvoir, VA, with Mr. T.C. Bowen, SATBE-FL, serving as the contracting officer's representative and Mr. M.E. LePera, SATBE-FL, serving as the technical monitor.

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I. INTRODUCTION/BACKGROUND

At the present time, engine oils conforming to Military Specifications MIL-L-2104 "Lubricating Oil, Internal Combustion Engine, Combat/Tactical Service " (1)*, MIL-L-21260 "Lubricating Oil, Internal Combustion Engine, Preservative and Break-In" (2), and MIL-L-46167 "Lubricating Oil, Internal Combustion Engine, Arctic" (3) are used in both the engines, transmissions/final drive, and selected hydraulic systems of Army ground equipment. This long-standing practice was introduced to reduce the logistical burden in supplying additional fluids to the field and to preclude the accidental and potentially disastrous effect of adding transmission/hydraulic fluids to the engine.

Recent developments in engine technology leading to higher operating temperatures, increased thermal-oxidative stress on engine oils, and new emission requirements in 1991 and 1994 have resulted in formulation changes in engine oils, which may make them less desirable as transmission/hydraulic/final drive fluids. Several manufacturers of Commercial Construction Equipment (CCE) no longer permit use of engine oils in transmissions of Commercial Construction Equipment and void the warranty if engine oil is used. A need for a separate military specification for a transmission/hydraulic fluid may exist. As a result, continued research and development in this area is critical.

The MIL-L-2104E specification requires the Caterpillar TO-2 (4) Friction Retention (Bronze) test and the Allison C-3 (5) Friction Retention (Graphite) test. Until recently, lubricants from both of these specifications could be used in the engine and powershift transmission/hydraulic systems as is allowed by MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications.

Caterpillar, Inc., which is developing a new TO-4 (6) specification for power transmission fluids, will require the use of these fluids in its transmissions only (not for engines). Caterpillar will no longer recognize the TO-2 specification for use in its transmission in 1991 as a result of a compatibility problem that had developed with fluoroelastomer material used in seals and clutch

* Underscored numbers in parentheses refer to the list of references at the end of this report.

plates of Caterpillar transmissions. Caterpillar feels that to be able to deliver maximum long-term performance with both the modern engine and transmission lubricants, separate and distinct lubricants must be used.(7)

During this program, Caterpillar made the decision to no longer support TO-2 friction testing, and no longer recommends the use of multigrade lubricants containing VI improvers for its powershift transmissions and final drives. In addition, the American Society for Testing and Materials (ASTM) TO-2 Surveillance Panel has voted to disband the panel. Also, Caterpillar has replaced the TO-2 Friction test with the TO-4 Friction Properties test, which uses one bronze, two fluoroelastomer, and three paper friction materials.

Allison Transmission Division (ATD) announced that the C-3 power transmission specification has been replaced by a new C-4 (8) power transmission specification and began recommending only C-4 fluids in late 1989. The C-4 specification has two Friction Retention tests. One test uses graphitic materials, and the other test uses paper composite materials. ATD plans to continue the use of engine oils in the transmissions, but it is, at the same time, introducing more fluoroelastomer material in its transmissions. The increased use of these materials could result in fluoroelastomer degradation problems similar to those experienced by Caterpillar. Therefore, ATD is developing a fluoroelastomer compatibility test in its C-4 specification. Any fluoroelastomer problems in the ATD transmissions could have a major impact on the U.S. Army, since the majority of the Army's tactical ground equipment powershift transmissions are manufactured by ATD and use engine oils as lubricants.

Also, the John Deere J20A multipurpose hydraulic/power transmission specification brake chatter test uses a paper asbestos brake material, but the John Deere construction equipment uses graphitic friction brake materials. Presently, John Deere is in the process of changing its friction brake materials.

These developments and actions require that the U.S. Army evaluate these new transmission fluids and multipurpose power transmission fluids being developed by industry to determine the acceptability of these fluids in Army combat/tactical ground equipment. The U.S. Army may also need to develop military specifications for the procurement of power transmission fluids that will satisfy manufacturers' warranty requirements if the performance of MIL-L-2104 cannot be modified to accommodate this changing requirement.

MIL-STD-838 (9), "Lubrication of Military Equipment," and doctrine states that petroleum logistics is most effective when the number of standard fuels and lubricants is kept to the absolute minimum that will still permit the required defense posture of the U.S. Army. To keep this number at a minimum, the type and number of fuels and lubricants required to support equipment must be controlled. Thus, maximum use will be made of standard specification products in the design and provision of new vehicles and equipment.

II. OBJECTIVES

The objective of this program was to investigate commercial/proprietary hydraulic/power transmission fluids to establish criteria for supporting the use of military specification products in satisfying manufacturer warranty requirements and fully meeting equipment lubrication needs.

III. APPROACH

The performance of this work, based on previous efforts conducted in this area (10-18), consisted of the following phased program:

- Selection of lubricants
- Solicitation and procurement of the lubricants
- Selection of chemical/physical/bench tests
- Test evaluation and data collection
- Select lubricants for performance evaluation tests
- Conduct performance tests.

A. Test Lubricants

Currently, a large number of proprietary multipurpose hydraulic/power transmission and final drive lubricants is available for equipment usage. Therefore, a wide variety of lubricants were selected for this program that satisfy both the manufacturers' warranty requirements and meet the needs of the Army ground/tactical equipment. To date, twenty lubricants were selected and obtained for evaluation. These lubricants were (1) commercially available and acceptable under proprietary specifications, (2) diesel engine/hydraulic/power transmission and final drive lubricants used in Army ground/tactical equipment and, (3) candidate arctic engine/hydraulic/power transmission lubricants. TABLE 1 lists the fluids/lubricants with BFLRF code and applicable specifications.

Of these 20 lubricants, six (Nos. 1 through 6) are proprietary multipurpose hydraulic/power transmission fluids, and five (Nos. 7, 8, 9, 17, and 19) are listed under MIL-L-2104 specification. Two lubricants (Nos. 15 and 16) are Caterpillar TO-4/TO-5 Heavy-Duty Powershift Transmission Oils, two (Nos. 11 and 14) are MIL-L-21260 lubricants, and one (No. 12) is a commercial CE, SAE grade 15W-40 lubricant. Also, three lubricants (Nos. 10, 18, and 20) are OEA-30 candidates, while lubricant No. 13 is a Super Tractor Oil Universal (STOU). The 20 lubricants include a wide variety of additive packages.

B. Test Selection

As shown in TABLE 2, no single common specification for hydraulic and power transmissions is used. The manufacturers of commercial construction and material-handling equipment issue and each use its own proprietary specification for hydraulic and power transmission lubricants, even though an American Society for Testing and Materials panel has developed a uniform specification for a multipurpose hydraulic/power transmission lubricant. The test procedures selected for this program were taken from an updated listing of the various manufacturers' requirements for hydraulic and power transmission lubricants (TABLE 3) as originally reported in Reference 14 in September 1982. These physical/chemical property and bench tests (TABLE 4) were selected because they were best suited to this program.

TABLE 1. Test Lubricants

Lube No.	BFLRF Code	Description/Specification	
1	AL-18614-L	Case/International (MHPT)	MS-1207
2	AL-18658-L	Ford/New Holland (MHPT)	M2C134
3	AL-18665-L	John Deere (MHPT)	JDM-J20A
4	AL-18669-L	John Deere (MHPT)	JDM-J20A
5	AL-18676-L	Massey-Ferguson (MHPT)	MF-1141
6	AL-18677-L	Massey-Ferguson (MHPT)	MF-1141
7	AL-18928-L	Army Qualified Product (SAE Grade 10W)	MIL-L-2104
8	AL-18927-L	Army Qualified Product (SAE Grade 30)	MIL-L-2104
9	AL-18750-L	Army Qualified Product (SAE Grade 15W-40)	MIL-L-2104
10	AL-18930-L	OEA-30 Candidate	Company A
11	AL-18955-L	Army Qualified Product (SAE Grade 10W)	MIL-L-21260
12	AL-18890-L	CE (SAE Grade 15W-40)	Commercial
13	AL-18891-L	Super Tractor Oil Universal (Engine, Transmission, Hydraulic, Gears)	STOU
14	AL-19026-L	Army Qualified Product (SAE Grade 15W-40)	MIL-L-21260
15	AL-18997-L	Caterpillar Powershift Transmission Fluid (SAE Grade 10)	TO-4/TO-5
16	AL-18985-L	Caterpillar Powershift Transmission Fluid (SAE Grade 30)	TO-4/TO-5
17	AL-19119-L	Allison Transmission Div. (C-4) Fluid/Army Qualified Product (SAE Grade 15W-40)	C-4/MIL-L-2104
18	AL-19392-L	OEA-30 Candidate	Company B
19	AL-19424-L	Allison Transmission Div. (C-4) Fluid/Army Qualified Product (SAE Grade 15W-40)	C-4/MIL-L-2104
20	AL-19528-L	OEA-30 Candidate	Company C

TABLE 2. Manufacturer and Lubricant Specifications

Manufacturer	Specification
Ford	ESN-M2C134-C (19)
John Deere	JDM-J20A (20)
Massey-Ferguson	MF-1141 (21)
Case International	MS-1207 (22)
Allison Transmission Div.	C-4
Caterpillar	TO-4/TO-5
Army	MIL-L-2104D SAE Grade 10W SAE Grade 30 SAE Grade 15W-40
	MIL-L-21260 SAE Grade 10W SAE Grade 15W-40
	MIL-L-46167 OEA-30 Candidate
API/SAE/ASTM	CE, SAE Grade 15W-40
Various	STOU (23)

TABLE 3. Listing of Suppliers of Hydraulic/Power Transmission Systems Fluid Requirements for Wheeled and/or Crawler Vehicles

Manufacturer Specification	Allison Chalmers PF 821	Allison Transmission C-4	Caterpillar TO-4/TO-5	J.I. Case TCH145	Deutz GL-4	John Deere JDM-J21A	Case/ International MS-1207
K. Vis., cSt, at 40°C	X*	X	X	NR	X	NR	NR
K. Vis., cSt, at 100°C	X	X	X	X	X	X	X
Viscosity Stability at 98.9°C (210°F)	NR	NR	NR	X	NR	X	X
Viscosity Index	NR	NR	X	X	X	NR	X
Apparent Vis., at -17.8°C (0°F)	X	X	X	X	NR	X	X
-28.9°C (-20°F)	NR	X	NR	NR	NR	NR	X
Flash Point, °C	NR	X	NR	X	NR	NR	NR
Fire Point, °C	NR	X	NR	X	NR	NR	NR
Pour Point, °C	X	X	X	X	X	X	X
Rust Protection	X	X	X	X	X	X	X
Corrosion	X	X	X	X	X	X	X
Antifoam	X	X	X	X	X	NR	X
Elastomers/Rubber Compatibility	X	X	X	X	X	X	X
Compatibility w/other Oils	X	NR	X	X	X	X	X
Oxidation & Thermal Stability	X	X	X	X	X	X	X
Friction, Clutch and/or Brake	NR	X	X	X	X	X	X
Transmission Durability	X	NR	NR	NR	X	X	X
Wear Protection	X	X	X	X	X	X	NR
Toxicity	NR	NR	NR	X	NR	NR	NR
API Gravity	NR	NR	X	NR	NR	NR	NR
Aniline Point	NR	NR	NR	NR	NR	NR	X
Color	NR	NR	NR	NR	NR	NR	X
Hydraulic Performance	NR	X	X	X	X	X	X
Metals	X	X	X	NR	NR	X	NR
Neutralization Number	NR	NR	NR	NR	NR	NR	NR
Odor	NR	NR	NR	NR	NR	NR	NR
Carbon Residue	NR	NR	X	NR	NR	NR	NR
Precipitation	NR	NR	NR	NR	NR	NR	NR
Stable Pour Point	NR	X	NR	NR	NR	NR	NR
Sulfur	NR	NR	NR	NR	NR	X	NR
Phosphorus	NR	NR	NR	NR	NR	X	NR
Chlorine	NR	NR	NR	NR	NR	X	NR
Nitrogen	NR	NR	NR	NR	NR	X	NR
Water Tolerance	NR	NR	X	NR	X	X	X
Dynamic Corrosion (Sundstrand)	NR	NR	NR	NR	X	NR	NR
Cold Oil Flowability	NR	NR	NR	NR	X	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	NR

* X = To Be Determined.
NR = Not Required.

TABLE 3. Listing of Suppliers of Hydraulic/Power Transmission Systems Fluid Requirements for Wheeled and/or Crawler Vehicles (Cont'd)

Manufacturer Specification	Massey-Ferguson MF-1141	Minneapolis Moline 35301	Oliver/White S-3727-B	Versatile JDM-J20A	Fiat-Allis GM-6137-M	Ford M2C134-C	ASTM Proposed
K. Vis., cSt, at 40°C	NR*	X	X	NR	NR	NR	NR
K. Vis., cSt, at 100°C	X	X	X	X	X	X	X
Viscosity Stability at 98.9°C (210°F)	X	X	NR	X	NR	X	X
Viscosity Index	X	X	NR	NR	NR	NR	NR
Apparent Vis. at							
-17.8°C (0°F)	X	X	NR	X	X	X	X
-28.9°C (-20°F)	NR	NR	NR	NR	X	NR	X
Flash Point, °C	NR	X	X	X	X	X	X
Fire Point, °C	NR	X	NR	NR	X	X	NR
Pour Point, °C	X	X	X	X	NR	X	NR
Rust Protection	X	X	NR	X	X	X	X
Corrosion	X	X	X	X	X	X	X
Antifoam	X	X	X	X	X	X	X
Elastomers/Rubber Compatibility	X	X	NR	X	X	X	X
Compatibility w/other Oils	NR	X	NR	X	X	X	NR
Oxidation & Thermal Stability	X	X	NR	X	X	X	X
Friction, Clutch and/or Brake	X	X	X	X	X	X	X
Transmission Durability	X	X	NR	X	X	X	NR
Wear Protection	X	X	NR	X	X	X	X
Toxicity	X	X	NR	NR	X	X	NR
API Gravity	NR	X	NR	NR	NR	NR	NR
Aniline Point	NR	X	NR	NR	NR	NR	NR
Color	NR	NR	X	NR	NR	NR	NR
Hydraulic Performance	NR	NR	NR	X	X	NR	X
Metals	NR	NR	NR	NR	NR	X	NR
Neutralization Number	NR	X	X	NR	NR	NR	NR
Odor	NR	X	NR	NR	NR	X	NR
Carbon Residue	NR	NR	NR	NR	NR	NR	NR
Precipitation	NR	X	NR	NR	NR	NR	NR
Stable Pour Point	NR	NR	NR	NR	NR	NR	NR
Sulfur	NR	X	NR	NR	NR	NR	NR
Phosphorus	NR	NR	NR	NR	NR	NR	NR
Chlorine	NR	NR	NR	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR	NR	NR	NR
Water Tolerance	NR	NR	NR	X	X	NR	X
Dynamic Corrosion (Sundstrand)	NR	NR	NR	NR	NR	NR	X
Cold Oil Flowability	NR	NR	NR	X	NR	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	X

* X = To Be Determined.
NR = Not Required.

TABLE 4. Chemical/Physical Properties and Bench Tests

a. Viscosity at 40° and 100°C (D 445)
b. Pour Point (D 97)
c. Foam Tendency [D 892A + Sequence 4 (MERCON)]
d. Copper Corrosion at 150°C (D 130)
e. TAN (D 664)
f. TBN (D 664)
g. Elastomer Compatibility (Buna N, Polyacrylate, Silicon, Fluoroelastomer) ATD C-4
h. Elemental (XRF and ICP)
i. Nitrogen (D 4629)
j. Tests on Selected Lubricants:
   - Viscosity at -40°C (D 455)
   - High-Temperature, High-Shear Viscosity (D 4683) (D 4628)
   - TFOUT (D 4742)
   - LUBTOT
   - ATD C-4 Pump Wear
   - ATD C-4 Friction Characteristics (Graphite)

Upon completion of the chemical/physical property and bench tests, the data were collected and tabulated. From these data, three lubricants (Nos. 10, 16, and 20) were selected in conjunction with Belvoir RDE Center for evaluation in the HT/HS Viscosity (D 4683), TFOUT (D 4742), LUBTOT (24), ATD C-4 Pump Wear and C-4 Friction Characteristics (Graphite) performance tests.

- TFOUT (D 4742) is used to evaluate oxidation stability of lubricating base oils with additives in the presence of chemistries similar to those found in engine service.

- HT/HS viscosity (D 4624) is used to measure the viscosity at or near the conditions of shear rate and temperature that will be experienced in severe service.

- LUBTOT is used to evaluate lubricant's performance in the amount of oil deposits formed on hot surfaces since excessive deposits can drastically shorten the life of power train systems.

- C-4 Pump Wear is used to measure wear characteristics of lubricants to protect pump and transmission components from excessive wear.

- C-4 Frictional Characteristics (Graphite) is used to measure the friction characteristics of power transmission lubricants on heavy-duty graphite-composite clutches.

IV. DISCUSSION OF RESULTS

The test lubricants were evaluated as they were received at BFLRF. Upon completion of the selected physical/chemical/bench tests, the test results from each lubricant were tabulated. These results are reported in TABLE 5. These results were then compared to the various proprietary and military specification for pass or fail results. Of the 20 lubricants evaluated, only five lubricants (Nos. 2, 14, 15, 16, and 19) passed all tests. The 15 failed lubricants included four failures with the copper corrosion test, six failures with the seal compatibility test, and eight failures with the foam characteristics test. The three OEA-30 candidate lubricants had two lubricants (Nos. 10 and 18) that failed both the pour point and the -40°C viscosity tests.

The results show that the lubricants that failed the copper corrosion test were lubricant Nos. 7, 8, 9, and 17. All four of these lubricants are MIL-L-2104 lubricants. No flaking was observed on any of the copper strips. MIL-L-2104, MIL-L-21260 and MIL-L-46167 specifications do not contain a copper corrosion requirement because no apparent copper corrosion problems have been observed in the field. These four lubricants also qualified as ATD C-3 fluids, which use the 100°C copper corrosion test temperature. The other MIL-L-2104 lubricant (No. 19) had passed the new ATD C-4 specification, which uses the copper corrosion test at the 150°C test temperature.

Five lubricants (Nos. 1, 8, 10, 12, and 18) failed the hardness change requirement of the total immersion test (ATD C-4). Lubricant No. 18 failed both the volume change and the hardness change of the total immersion test, and lubricant No. 20 had a borderline fail with the total immersion hardness change test. Note that lubricant Nos. 10, 18, and 20 are OEA-30 candidate grade synthetic blend lubricants; the Army synthetic lubricants (MIL-L-46167) have traditionally had problems with the seal compatibility tests.

Lubricant No. 3 failed both Sequences I and III of the foam test; four lubricants (Nos. 4, 5, 6, and 13) failed Sequences II and IV of the foam test; and three lubricants (Nos. 10, 11, and 12)

TABLE 5. Chemical and Physical Properties Test Results

Lubricant No.	Viscosity, cSt, D 445				Pour Point, °F, D 97	Copper Corrosion, 150°C, D 130	TAN, D 664	TBN, D 664	ICP, ppm										CLM*, %	XRF**, %
	40°C	100°C	VI	-40°C					Ba	B	Ca	Mg	Mn	Mo	Ni	Na	P	Zn	N	S
1	39.31	6.27	107	--	-36	1B	1.4	5.3	<1	<1	4014	8	<1	<1	1	146	2713	17	0.011	0.27
2	58.55	9.26	139	--	-31	1A	2.5	12.8	<1	97	3893	16	<1	<1	1	19	1149	1381	0.014	0.45
3	59.67	9.89	152	--	-33	1A	2.8	10.0	<1	<1	3061	9	<1	<1	<1	68	1017	1282	0.014	0.43
4	58.07	9.47	146	--	-34	1A	2.6	11.1	<1	102	3799	15	<1	<1	1	8	1113	1401	0.015	0.42
5	58.87	9.12	134	--	-28	1A	2.7	10.6	<1	104	3855	24	<1	<1	1	8	1124	1480	0.013	0.45
6	57.93	9.43	145	--	-29	1A	2.8	13.0	<1	<1	41	3840	<1	10	1	13	1068	748	0.018	0.43
7	41.61	6.61	111	--	-30	(4C)	2.4	6.5	<1	12	15	1270	<1	2	<1	5	928	1000	0.044	0.67
8	92.18	11.04	105	--	-23	(4C)	2.7	6.8	<1	15	32	1368	<1	2	<1	2	1056	1110	0.050	0.77
9	104.42	13.80	133	--	-22	(4B)	2.9	8.3	13	171	25	1087	<1	2	<1	4	777	818	0.047	0.49
10	57.48	19.70	180	+	(-40)	1A	2.6	6.7	<1	<1	1901	650	1	3	<1	11	954	1029	0.057	0.37
11	38.74	6.47	119	--	-30	1B	3.6	6.2	<1	4	1608	414	<1	2	<1	23	1219	1967	0.030	1.04
12	102.86	14.52	145	--	-29	1A	2.7	8.2	<1	5	2212	8	<1	2	<1	17	1234	1356	0.092	0.55
13	80.82	11.31	130	--	-28	1B	3.8	9.2	<1	<1	5056	11	1	3	<1	91	1506	1237	0.079	0.40
14	111.08	14.59	135	--	-31	1A	3.7	7.4	<1	3	1640	438	<1	<1	<1	21	1162	1704	0.034	1.10
15	38.50	6.19	107	--	-33	1B	1.7	5.8	<1	<1	3294	4	<1	<1	2	34	605	590	0.008	0.43
16	103.25	11.57	99	--	-32	1B	1.7	7.9	<1	<1	3241	8	<1	1	1	27	629	581	0.011	0.48
17	101.15	14.58	149	--	-23	(4A)	3.7	6.4	4	244	944	840	<1	<1	<1	1	968	1084	0.115	0.56
18	48.12	10.46	214	26,463	(-54)	1A	2.6	5.0	4	345	2900	1	1	<1	<1	5	1075	1234	0.064	0.32
19	107.24	14.03	13	--	-27	1A	2.4	6.4	<1	117	1798	483	<1	<1	<1	15	985	1090	0.056	0.59
20	54.78	11.01	198	14,517	-55	1A	2.5	6.4	<1	207	2144	8	<1	<1	<1	19	1194	1080	0.151	0.30

* CLM = Chemiluminescence.
** XRF = X-ray fluorescence.
( ) Indicates fail.
\+ Could not obtain a valid viscosity at -40°C.

TABLE 5. Chemical and Physical Properties Test Results (Cont'd)

Lubricant	ICP,		Seal Compatibility								Foam Characteristics, mL							
No.	ppm		Total Immersion		Dip Cycle		Tip Cycle		Fluoroelastomer		Seq. I		Seq. II		Seq. III		Seq. IV	
	Cu	Si	Volume Change	Hardness Change	Volume Change	Hardness Change	Volume Change	Hardness Change	Volume Change	Hardness Change	5-Min. Blow	1-Min. Settle	5-Min. Blow	1-Min. Settle	5-Min. Blow	1-Min. Settle	5-Min. Blow	1-Min. Settle
1	<1	<1	+5.95	(+7)	+7.42	-3	+3.76	-1	+2.19	-1	0	0	20	0	0	0	30	0
2	<1	4	+1.66	0	+3.76	-1	+3.40	-2	+1.23	0	0	0	0	0	0	0	0	0
3	<1	<1	+3.12	-2	+5.48	-3	+3.88	-2	+1.57	-1	(70)	(30)	30	0	(100)	(40)	30	0
4	<1	<1	+1.79	-2	+3.96	-2	+3.50	-2	+3.50	-2	0	0	(200)	(10)	0	0	(310)	140
5	<1	<1	+1.68	0	+4.17	-2	+3.40	-2	+1.28	+1	0	0	(220)	(60)	0	0	(390)	90
6	<1	4	+1.60	-1	+3.99	-2	+3.36	-2	+1.38	0	0	0	(270)	(160)	0	0	(340)	90
7	1	<1	+2.51	+4	+4.69	-1	+3.68	-2	+1.19	+2	0	0	20	0	0	0	80	0
8	1	1	+0.86	(+7)	+3.01	0	+2.23	-1	+0.70	+3	0	0	10	0	0	0	20	0
9	1	<1	+2.31	-2	+4.02	-2	+3.44	-2	+1.04	+2	0	0	30	0	0	0	60	0
10	<1	2	+1.07	(+7)	+4.56	-2	+4.42	-2	+1.80	+1	0	0	40	0	0	0	(110)	0
11	<1	2	+5.21	0	+6.26	-3	4.43	-2	+1.55	+2	0	0	40	0	0	0	(110)	0
12	<1	<1	+1.74	(+7)	+4.04	0	+3.28	-2	+1.01	+3	0	0	30	0	0	0	(110)	0
13	<1	<1	+1.89	+2	+4.41	-2	+2.97	-2	+0.87	+2	0	0	(290)	(120)	0	0	(330)	0
14	<1	1	+4.30	0	+5.38	-4	+3.38	-2	+1.07	+2	0	0	0	0	0	0	0	0
15	<1	<1	+1.70	0	+4.48	-2	+3.78	-2	+1.35	0	0	0	0	0	0	0	0	0
16	<1	<1	+0.12	0	+3.15	-2	+2.24	-1	+0.81	+1	0	0	0	0	0	0	0	0
17	1		+4.22	+4	+6.02	-5	+3.39	-2	+1.21	+2	0	0	0	0	0	0	70	0
18			(-0.91)	(+11)	+3.25	+2	+4.31	-2	+0.75	+3	0	0	60	0	0	0	100	0
19	<1		+1.68	+4	+4.16	-1	+3.03	-2	+0.71	+2	0	0	0	0	0	0	0	0
20	<1		+3.87	+4	+8.32	(-6)	+4.89	-2	+2.66	+1	0	0	0	0	0	0	80	0
MIL-L-2104E			+0.75 to +6.75	0 ± 5	0 to +10	-5 to 0	+1.5 to +6.5	-10 to 0	+	+	25	0	150	0	25	0	+	+
C-4 Acceptable Adjusted Limits			+0.75 to +6.75	0 ± 5	0 to +10	-5 to 0	+1.5 to +6.5	-10 to 0	•	•								
C-4 and MERCON											100	0	100	0	100	0	100	0

+ Not part of MIL-L-2104 specification.
• Report limits not established.
( ) Indicates fail.

failed only Sequence IV of the foam test. The MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications do not, as yet, have a requirement for the Sequence IV foam test.

Of the three OEA-30 candidate lubricants (Nos. 10, 18, and 20), Nos. 10 and 18 failed the pour point of -55°C with -40° and -54°C, respectively. Both of these lubricants also failed the temporary -40°C viscosity of 15,000 to 16,000 cSt maximum.

Those lubricants that failed more than one test include: Lubricant No. 8 failed two tests, the copper corrosion and the seal compatibility tests; lubricant No. 12 failed two tests, the seal compatibility and foam characteristics tests; lubricant No. 18 failed three tests, the seal compatibility and two cold temperature tests at -40°C, viscosity and pour point tests; lubricant No. 10 failed four tests, the seal compatibility, foam characteristics, and the cold temperature tests at -40°C, viscosity and pour point tests.

From the data in TABLE 5, BFLRF, in concert with Belvoir RDE Center personnel, selected lubricants Nos. 10, 16, and 20 for additional evaluation. The additional bench and performance tests included the HTHS Viscosity (D 4683), TFOUT (D 4742), LUBTOT, ATD C-4 Pump Wear, and C-4 Friction Characteristics (Graphite) tests.

Lubricant No. 10, the OEA-30 candidate, was selected even though the lubricant failed the -40°C viscosity, seal compatibility (Total Immersion), and Sequence IV Foam tests. The manufacturer has blended a candidate lubricant that has the same basic additive package as Lubricant No. 10 but with improved cold flowability, seal and foam characteristics. This new candidate will be evaluated upon receipt at BFLRF. Lubricant No. 16 is the Caterpillar TO-4/TO-5 service fill fluid and is of interest because Caterpillar no longer recommends engine lubricants or lubricants containing viscosity improvers for use in its heavy-duty powershift transmissions and in many final drive gear boxes. Lubricant No. 20 is the best OEA-30 candidate evaluated in the chemical/physical property tests. The results for the HTHS viscosity, TFOUT and LUBTOT tests are shown in TABLE 6 and again lubricant No. 20 appears to be the best.

TABLE 6. Performance Bench Tests

Lube No.	Lube Code	HTHS Viscosity at 150°C	TFOUT, min.	LUBTOT at 600°F, Deposit Volume, $cm^3 \times 10^{-7}$
10	AL-18930-L	3.21	212	9,604
16	AL-18986-L	2.97	248	11,591
20	AL-19528-L	3.08	>500	2,412

The results from the ATD C-4 pump wear and friction characteristics (Graphite) tests are reported in TABLES 7 and 8. All three lubricants (Nos. 10, 16, and 20) passed the C-4 pump wear test. Lubricant Nos. 10 and 16 passed the friction characteristics test, but Lubricant No. 20 was a borderline fail in slip time and midpoint friction of the C-4 friction characteristics test. The complete C-4 pump wear and friction characteristics test data are included in the Appendix.

TABLE 7. ATD C-4 Pump Wear Test

Lube No.	Lube Code	Pattern, %	Scratching	Scoring	Pitting	Burning	Discoloration	Test Result
10	AL-18930-L	100	None	None	None	None	Light	Pass
16	AL-18986-L	100	Light	None	None	None	Light	Pass
20	AL-19528-L	100	Light	None	None	None	None	Pass

TABLE 8. ATD C-4 Friction Characteristics (Graphite)

Lube No.	Lube Code	Slip Time, sec.	Midpoint Friction	Steel Plates Avg, in.	Clutch Plate Avg. in.	Pack Clearance, in.	Test Result
10	AL-18930-L	0.72	0.100	0.0004	0.0040	0.020	Pass
16	AL-18986-L	0.66	0.108	0.0002	0.0030	0.022	Pass
20	AL-19528-L	(0.76)	(0.094)	0.0003	0.0020	0.020	Fail

( ) Indicates Fail.

V. CONCLUSIONS

A. General

After evaluating the 20 selected lubricants, comparing these results with various commercial/proprietary hydraulic/power transmission tests, and discussing these data with personnel from Caterpillar and Allison Transmission Division, the results show that the MIL-L-2104 and MIL-L-21260 specification lubricants can satisfy all the manufacturers' warranty requirements and still meet the Army's ground vehicle/equipment lubrication needs. The military specification lubricants are judged to be acceptable, particularly if the TO-2 friction test is upgraded to the TO-4 sintered bronze friction test, the C-3 friction test is upgraded to the C-4 friction tests, and requirements for the C-4 copper corrosion tests, the C-4 and/or TO-3 fluoroelastomer seal tests, and C-4 or MERCON Sequence IV foam tests are added. This work also shows that it is possible to develop a multipurpose OEA-30 lubricant that can operate in the Arctic and warmer climates in hydraulic/power transmission and final drive systems of Army combat/tactical ground equipment than is currently specified in MIL-L-46167. The developed OEA-30 lubricant will aid in the logistics by removing two lubricant grades and one specification from the Qualified Products List.

B. Specific

- The problem area of the multipurpose hydraulic/power transmission fluids (Lubricant Nos. 1 through 6) appears to be foaming. Of the six fluids, four failed part of the foaming test.

- For the 20 test lubricants, 8 failed part of the foam test.

- The five MIL-L-2104 lubricants (Nos. 7, 8, 9, 17, and 19) were evaluated. Of these lubricants, four failed the copper corrosion test at 150°C, while No. 8 also failed the total immersion hardness change part of the seal test, and one lubricant (No. 19) passed all physical/chemical tests and is also a qualified C-4 lubricant.

- Five lubricants (Nos. 1, 8, 10, 12, and 18) failed the C-4 seal compatibility tests.

- The two Caterpillar TO-4/TO-5 powershift transmission fluids (Lubricant Nos. 15 and 16) passed all physical and chemical tests, but Lubricant No. 16 had the highest deposits in the LUBTOT. These lubricants are not for engine usage.

- The two MIL-L-21260 preservative lubricants passed all physical and chemical tests with the exception of the 10W grade lubricant, which failed the Sequence IV part of the foaming test. There is no Sequence IV foam test in the MIL-L-21260 specification.

- Lubricants designed for only power transmission usage appear to produce a slightly higher level of transmission performance than the MIL-L-2104 lubricants because they passed all the hydraulic and power transmission tests.

VI. RECOMMENDATIONS

- The majority of the combat/tactical ground vehicle heavy-duty powershift transmissions use ATD transmissions that predominantly use bronze friction disc material. The ATD C-4 friction tests use graphite and paper friction materials for qualification. It appears that the Army is without a test to evaluate the bronze friction discs for its power transmissions. Even if the TO-4 bronze friction test is conducted, there is no correlation between this test and the performance of the bronze disc in Allison power transmissions. Therefore, it is recommended that a correlation be developed between the TO-4 bronze friction test and the C-4 paper and graphitic friction tests and/or develop a friction test for ATD transmission bronze friction material. In addition, it is recommended that a correlation be developed between the C-4 and TO-4 friction tests and the John Deere brake chatter test. Also until this correlation has been established, it is recommended that the TO-2 and C-3 friction tests be upgraded to the TO-4 and C-4 friction tests for the Army MIL-L-2104, MIL-L-21260, and MIL-L-46167 specifications.

- The MIL-L-46167 arctic lubricant specification has a maximum viscosity at -40°C of 8,800 cSt, while the OEA-30 candidate lubricants have a -40°C viscosity of 14,000 to 16,000 cSt. Therefore, it is recommended that low-temperature power transmission flowability/pumpability studies be conducted.

- It is also recommended to add a copper corrosion test to prevent copper corrosion, even though no apparent corrosion problems have been observed in the field. This test is necessary because of increased operating temperatures, and the MIL-L-2104, MIL-L-21260, and MIL-L-46167 have no copper corrosion tests in their specification. It will be necessary to add the C-4 and/or TO-3 fluoroelastomer seal tests. It is additionally recommended that the Sequence IV foam test be added to Army lubricant specifications MIL-L-2104, MIL-L-21260, and MIL-L-46167. With the addition of the above-recommended work, an OEA-30 hydraulic, power transmission and final drive lubricant can be developed for Army combat/tactical use.

- Caterpillar, Allison Transmission Division, and John Deere Co. have expressed concern about transmission/fluid drive wear because only the Army MIL-L-46167 lubricant has a transmission wear test, while MIL-L-2104 and MIL-L-21260 do not. To date, the Army lubricants have had positive results in the transmission/final drive wear area. However, with the new engine lubricant formulations becoming available to meet the 1994 heavy-duty diesel exhaust emission requirements, it appears it is necessary for the Army to conduct further research in transmission/final drive wear on the MIL-L-2104, MIL-L-21260, and MIL-L-46167 specification lubricants using the appropriate wear tests (pump wear and/or gear wear).

VII. LIST OF REFERENCES

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APPENDIX

C-4 Pump Wear and Friction Characteristics Test Data

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 WEAR TEST

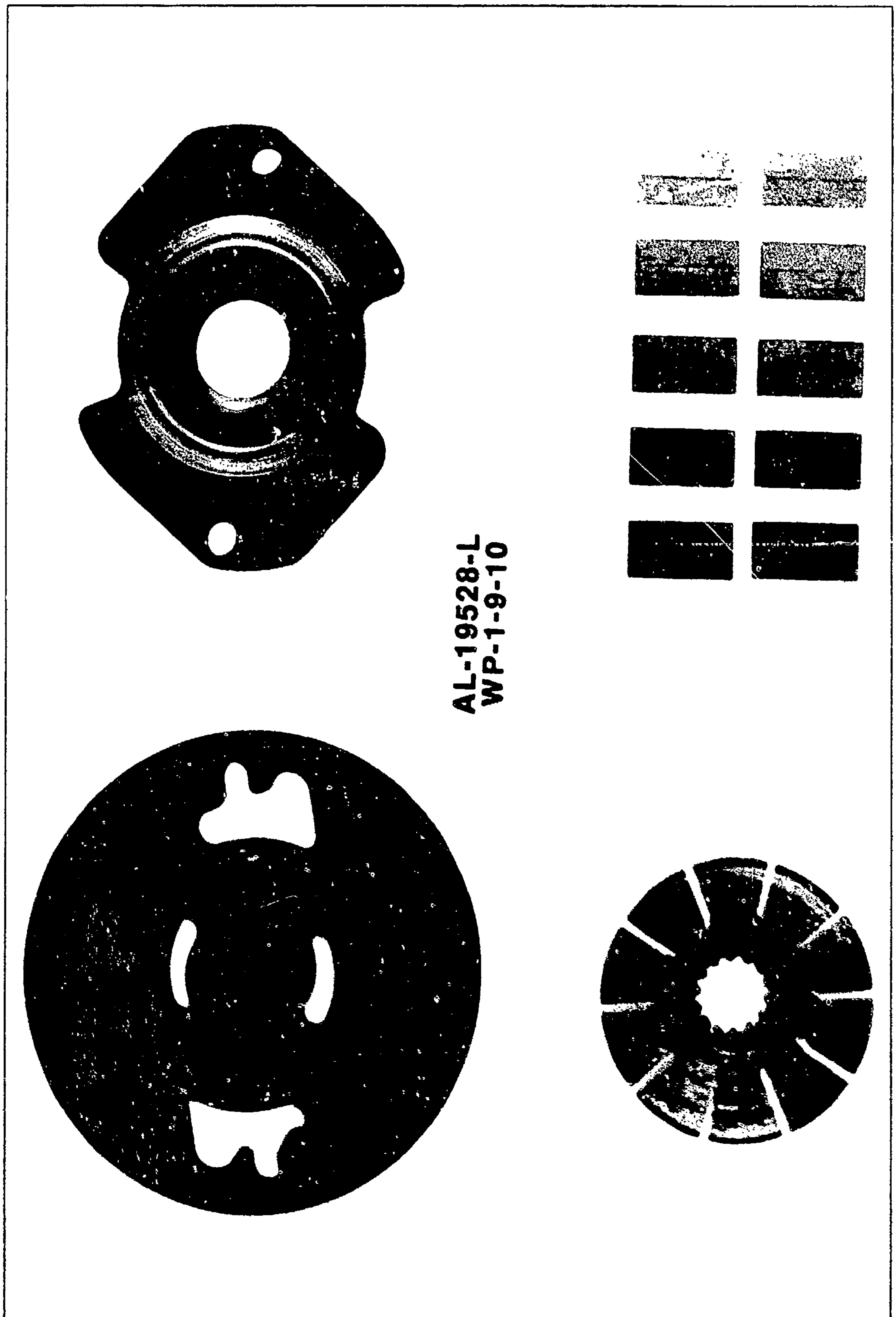
Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

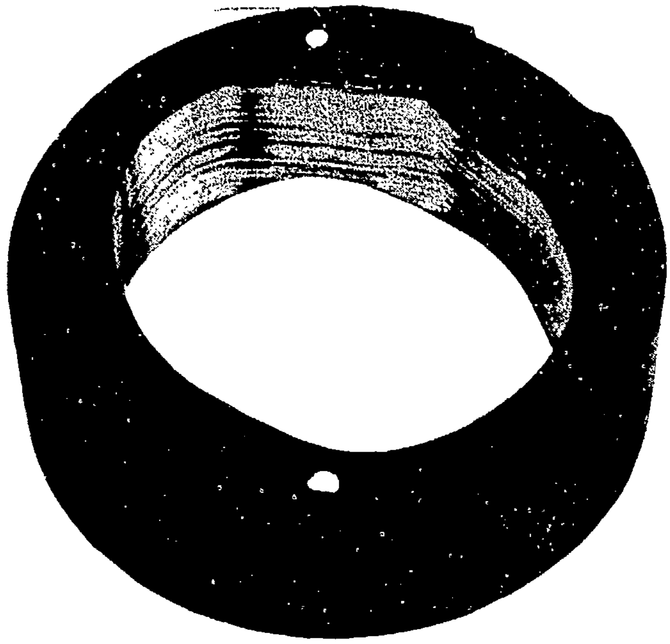
AL-19528-L
Test Number: WP-1-9-10

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

December 5, 1990


AL-19528-L
WP-1-9-10

AL-19528-L
WP-1-9-10



AL-19528-L
WP-1-9-10

C-4 HEAVY-DUTY TRANSMISSION FLUID SPECIFICATION

ALLISON TRANSMISSION DIVISION GENERAL MOTORS

VII. POWER STEERING PUMP WEAR TEST

TESTING LABORATORY:	SwRI	LAB FLUID CODE:	---
TEST NUMBER:	WP-1-9-10	SPONSOR FLUID CODE:	AL-19528-L

CHEMICAL ANALYSIS

SILICON ICP --- ppm

	METHOD	RESULTS	UNITS
BARIUM	ICP	---	ppm
BORON	ICP	---	ppm
CALCIUM	ICP	---	ppm
MAGNESIUM	ICP	---	ppm
PHOSPHORUS	ICP	---	ppm
SODIUM	ICP	---	ppm
ZINC	ICP	---	ppm
* VISCOSITY AT 40 °C	D445	---/35.76	cSt
* VISCOSITY AT 100 °C	D445	---/6.95	cSt

ALUMINUM*	ICP	<1	ppm
COPPER*	ICP	2	ppm
LEAD*	ICP	1	ppm
TIN*	ICP	3	ppm

*END

* START/END

(ATD USE ONLY)

MAX	MIN

CAM RING INSPECTION

	NONE	LIGHT	MEDIUM	HEAVY	COMMENTS
SCRATCHING		X			
SCORING	X				
PITTING	X				
BURNING	X				
DISCOLORATION	X				

GRINDING MARKS

% PATTERN REMAINING 100 %

IRON CONTENT	
INITIAL	FINAL
---	16

RECOMMENDED RATING PASS	RECOMMENDED RATING FAIL	(ATD USE ONLY) PASS	(ATD USE ONLY) FAIL
X			

IRON CONTENT	
INITIAL	FINAL

INCLUDE CAM RING PHOTO WITH TEST REPORT.

TEST SUMMARY

	UNITS	MINIMUM	MAXIMUM	AVERAGE
TEMPERATURE	°F	135	137	136
FLUID PRESSURE	PSI	6198	6224	6212
PUMP OUT TEMPERATURE	°F	145	146	145

NAME: Raymond D. Townsend, Jr.

DATE: December 5, 1990

TITLE: Group Leader

SINGATURE: Raymond D. Townsend Jr.

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 WEAR TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18986-L
Test Number: WP-1-10-11

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

December 16, 1990

C-4 HEAVY-DUTY TRANSMISSION FLUID SPECIFICATION	ALLISON TRANSMISSION DIVISION GENERAL MOTORS

VII. POWER STEERING PUMP WEAR TEST

TESTING LABORATORY:	SwRI	LAB FLUID CODE:	---
TEST NUMBER:	WP-1-10-11	SPONSOR FLUID CODE:	AL-18986-L

CHEMICAL ANALYSIS

	METHOD	RESULTS	UNITS					MAX (ATD USE ONLY)	MIN (ATD USE ONLY)
SILICON	ICP	---	ppm						
BARIUM	ICP	---	ppm	ALUMINUM*	ICP	1	ppm		
BORON	ICP	---	ppm	COPPER*	ICP	1	ppm		
CALCIUM	ICP	---	ppm	LEAD*	ICP	1	ppm		
MAGNESIUM	ICP	---	ppm	TIN*	ICP	3	ppm		
PHOSPHORUS	ICP	---	ppm						
SODIUM	ICP	---	ppm	*END					
ZINC	ICP	---	ppm						
* VISCOSITY AT 40 °C	D445	103.49	cSt						
* VISCOSITY AT 100 °C	D445	11.58	cSt						

* START/END

CAM RING INSPECTION

	NONE	LIGHT	MEDIUM	HEAVY	COMMENTS
SCRATCHING	☐	☒	☐	☐	
SCORING	☐	☐	☐	☐	
PITTING	☐	☐	☐	☐	
BURNING	☐	☐	☐	☐	
DISCOLORATION	☐	☒	☐	☐	

GRINDING MARKS

% PATTERN REMAINING 100 %

IRON CONTENT	
INITIAL	FINAL
	4

•RECOMMENDED RATING PASS	•RECOMMENDED RATING FAIL	(ATD USE ONLY) PASS	(ATD USE ONLY) FAIL
☒	☐	☐	☐

INCLUDE CAM RING PHOTO WITH TEST REPORT.

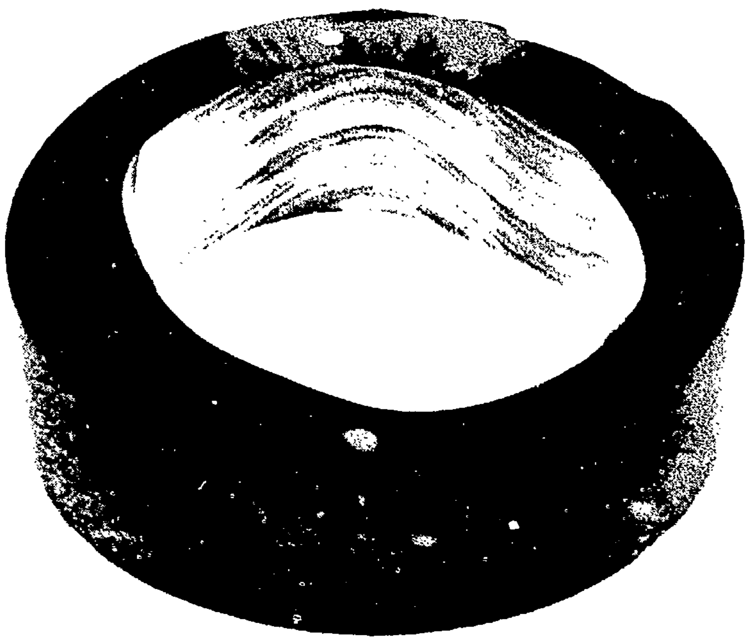
TEST SUMMARY

	UNITS	MINIMUM	MAXIMUM	AVERAGE
TEMPERATURE	°F	137	139	138
FLUID PRESSURE	PSI	6212	6252	6232
PUMP OUT TEMPERATURE	°F	146	149	148

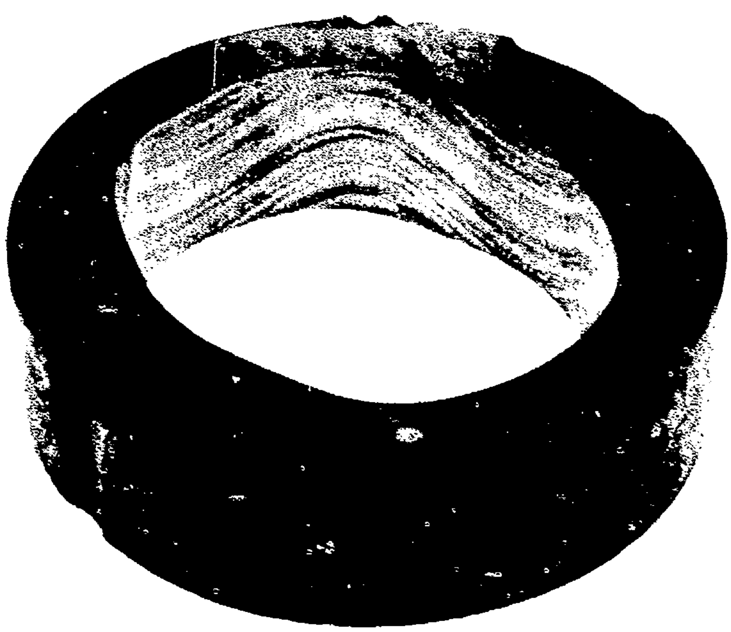
NAME: Raymond D. Townsend, Jr.   DATE: December 16, 1990

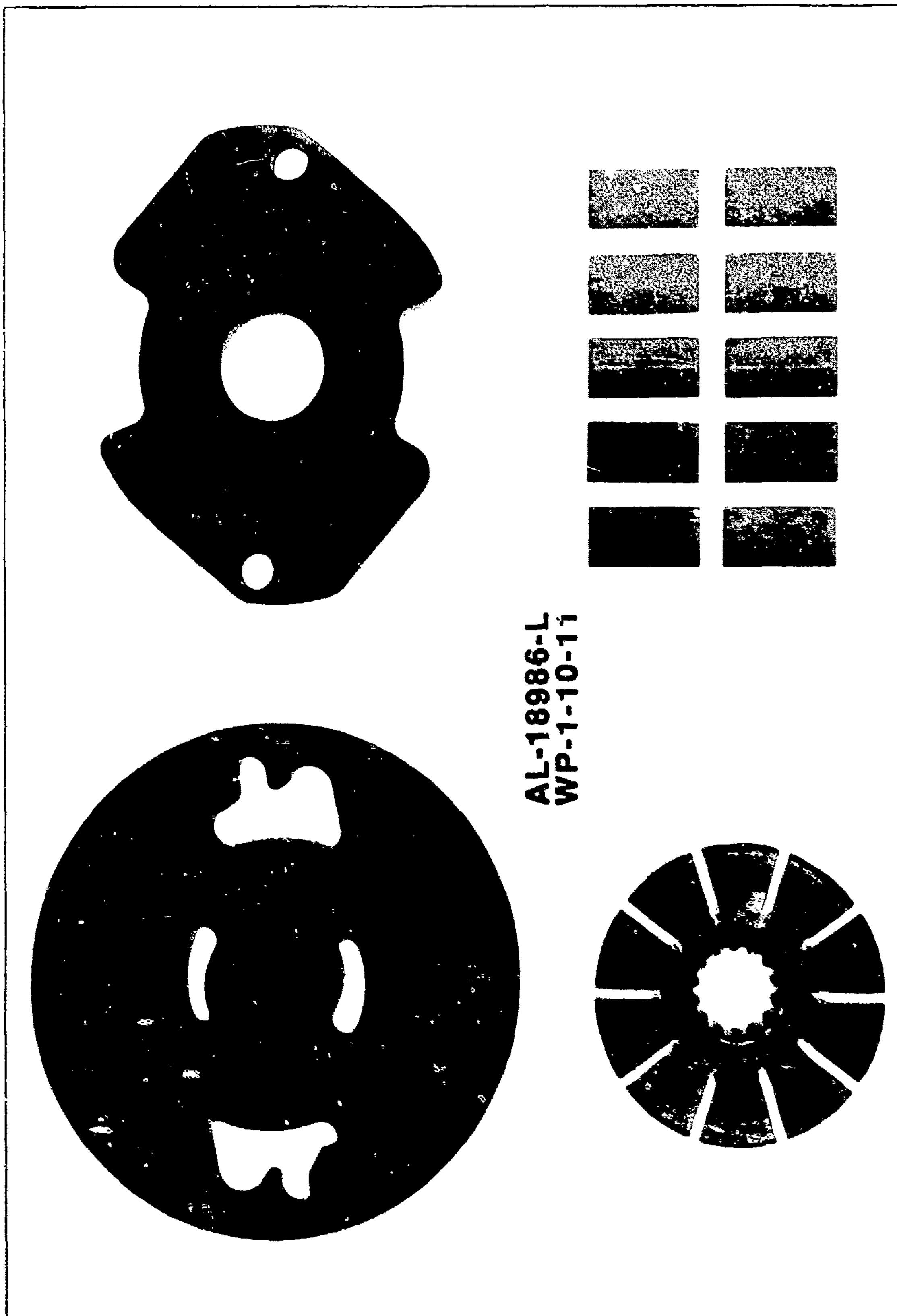
TITLE: Group Leader   SINGATURE: Raymond D. Townsend Jr.

AL-18986-L
WP-1-10-11



AL-18986-L
WP-1-10-11




AL-18986-L
WP-1-10-11

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 WEAR TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18930-L
Test Number: WP-1-1-13

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

December 22, 1990

C-4 HEAVY-DUTY TRANSMISSION FLUID SPECIFICATION	ALLISON TRANSMISSION DIVISION GENERAL MOTORS

VII. POWER STEERING PUMP WEAR TEST

TESTING LABORATORY:	SwRI	LAB FLUID CODE:	---
TEST NUMBER:	WP-1-1-13	SPONSOR FLUID CODE:	AL-18930-L

CHEMICAL ANALYSIS

	METHOD	RESULTS	UNITS					MAX (ATD USE ONLY)	MIN (ATD USE ONLY)
SILICON	ICP	---	ppm						
BARIUM	ICP	---	ppm	ALUMINUM*	ICP	2	ppm		
BORON	ICP	---	ppm	COPPER*	ICP	1	ppm		
CALCIUM	ICP	---	ppm	LEAD*	ICP	<1	ppm		
MAGNESIUM	ICP	---	ppm	TIN*	ICP	3	ppm		
PHOSPHORUS	ICP	---	ppm						
SODIUM	ICP	---	ppm	*END					
ZINC	ICP	---	ppm						
* VISCOSITY AT 40 °C	D445	42.51	cSt						
* VISCOSITY AT 100 °C	D445	8.08	cSt						

* START/END

CAM RING INSPECTION

	NONE	LIGHT	MEDIUM	HEAVY	COMMENTS
SCRATCHING	X				
SCORING	X				
PITTING	X				
BURNING	X				
DISCOLORATION		X			

GRINDING MARKS

% PATTERN REMAINING 100 %

IRON CONTENT	
INITIAL	FINAL
---	13

RECOMMENDED RATING PASS	RECOMMENDED RATING FAIL	(ATD USE ONLY) PASS	(ATD USE ONLY) FAIL
X			

INCLUDE CAM RING PHOTO WITH TEST REPORT.

TEST SUMMARY

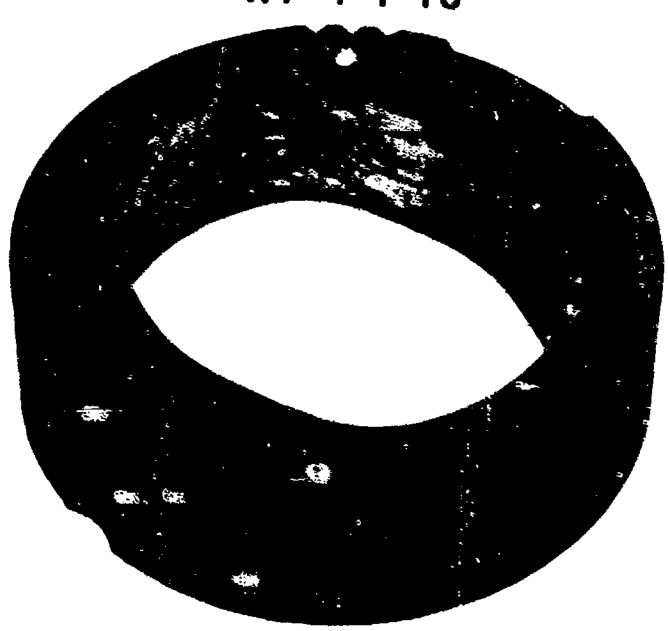
	UNITS	MINIMUM	MAXIMUM	AVERAGE
TEMPERATURE	°F	135	139	137
FLUID PRESSURE	PSI	6196	6214	6214
PUMP OUT TEMPERATURE	°F	145	149	147

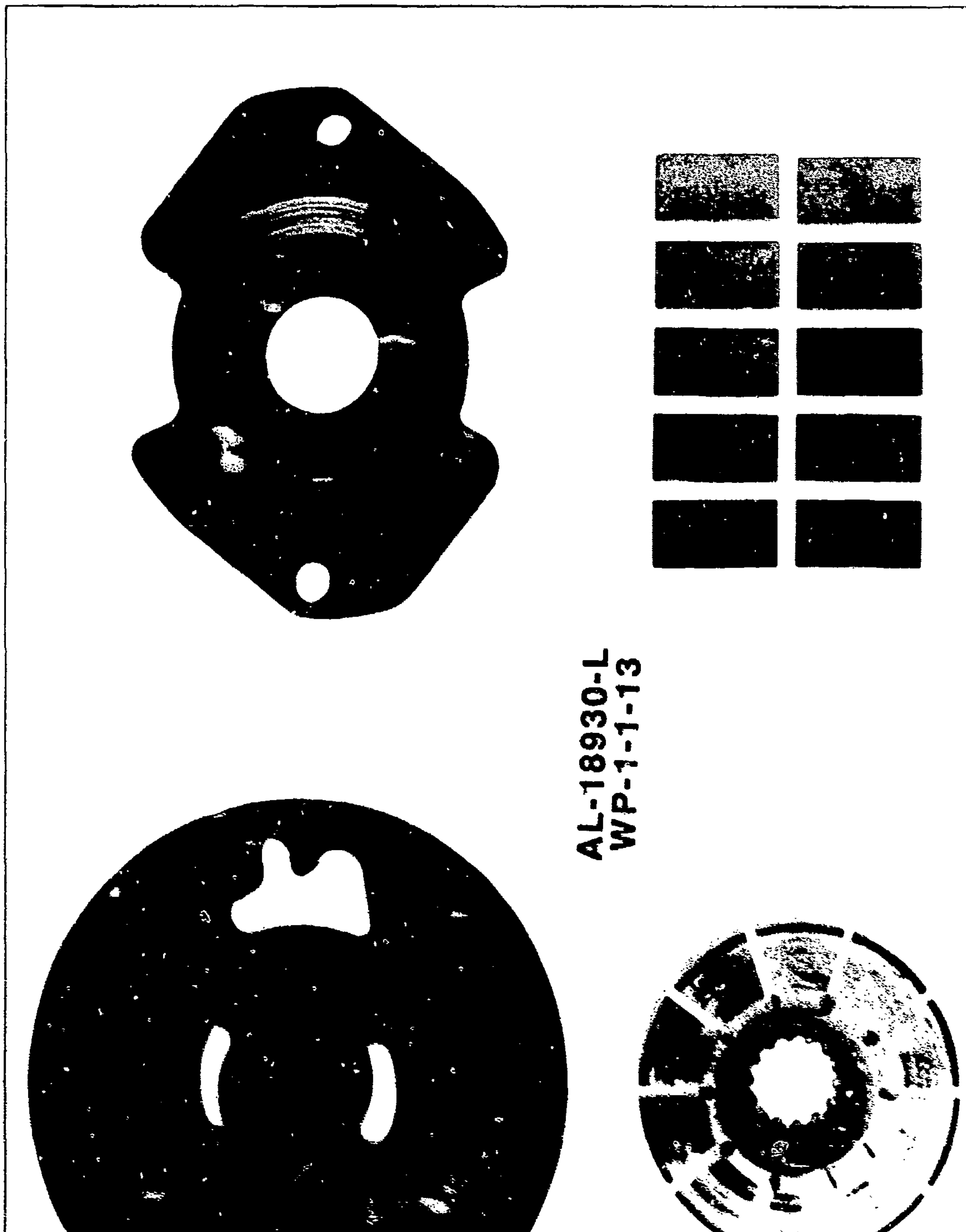
NAME: Raymond D. Townsend, Jr. DATE: December 22, 1990

TITLE: Group Leader SINGATURE: Raymond D. Townsend

AL-18930-L
WP-1-1-13

AL-18930-L
WP-1-1-13




AL-18930-L
WP-1-1-13

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALL. 3ON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18986-L
Run Number: C7-8-83

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

January 7, 1991

C-4 HEAVY-DUTY TRANSMISSION FLUID SPECIFICATION	ALLISON TRANSMISSION DIVISION GENERAL MOTORS

VIII. GRAPHITE CLUTCH FRICTION TEST REPORT

TESTING LABORATORY:	SwRI	SPONSOR FLUID CODE:	AL-18986-L
TEST NUMBER:	C7-8-83	LAB FLUID CODE:	---

FRICTION PLATE BATCH No:	31
STEEL PLATE BATCH No:	Dec 21 89

CHEMICAL ANALYSIS

	METHOD	RESULTS	UNITS	ATD USE ONLY MAX	ATD USE ONLY MIN
SILICON	ICP	---	ppm		
BARIUM	ICP	---	ppm		
BORON	ICP	---	ppm		
CALCIUM	ICP	---	ppm		
MAGNESIUM	ICP	---	ppm		
PHOSPHORUS	ICP	---	ppm		
SODIUM	ICP	---	ppm		
ZINC	ICP	---	ppm		
* VIS @ 40 C	ASTM D445	---/100.30	cst		
* VIS @ 100 C	ASTM D445	---/11.37	cst		
* IRON	ICP	---/29	ppm		

* START/END

FRICTION CHARACTERISTICS

	LIMITS 5,500 N	LIMITS % CHANGE	RESULTS :,500	RESULTS 5,500 N	RESULTS % CHANGE	PASS	FAIL
SLIP TIME (SECONDS)	0.74 max	---	0.66	0.66	0.000	X	
0.2-SECONDS DYNAMIC COEFFICIENT	---	---	0.111	0.106	4.50		
MID-POINT FRICTION COEFFICIENT	0.096 min	---	0.111	0.108	2.70	X	
STATIC FRICTION COEFFICIENT	---	---	0.145	0.141	2.76		
LOW SPEED PEAK FRICTION COEFF.	---	---	0.150	0.141	6.00		
.25 SECOND LOW SPEED COEFF.	---	---	0.150	0.139	7.33		

CLUTCH WEAR DATA

	MAXIMUM WEAR LIMITS	MAXIMUM WEAR RESULTS	AVERAGE WEAR LIMITS	AVERAGE WEAR RESULTS	PASS	FAIL
STEEL PLATES (2)	---	0.0003	---	0.0002		
CLUTCH PLATE (1)	---	0.0039	---	0.0030		
PACK CLEARANCE	BEFORE	0.018	AFTER	0.022		

REFERENCE TESTS

TEST NUMBER	TEST DATE	TEST FLUID
C7-0-16	05-23-90	03A-PASS-1
C7-0-29	06-21-90	03A-PASS-L
C7-0-70	12-04-90	03A-PASS-L
C7-0-75	12-18-90	03A-PASS-L

NAME: Raymond D Townsend, Jr.

SIGNATURE:

TITLE: Group Leader

DATE: January 7, 1991

C-4

CLUTCH PACK IDENTIFICATION AND INSPECTION
FOR FRICTION MODIFIED FLUIDS

Date: January 7, 1991

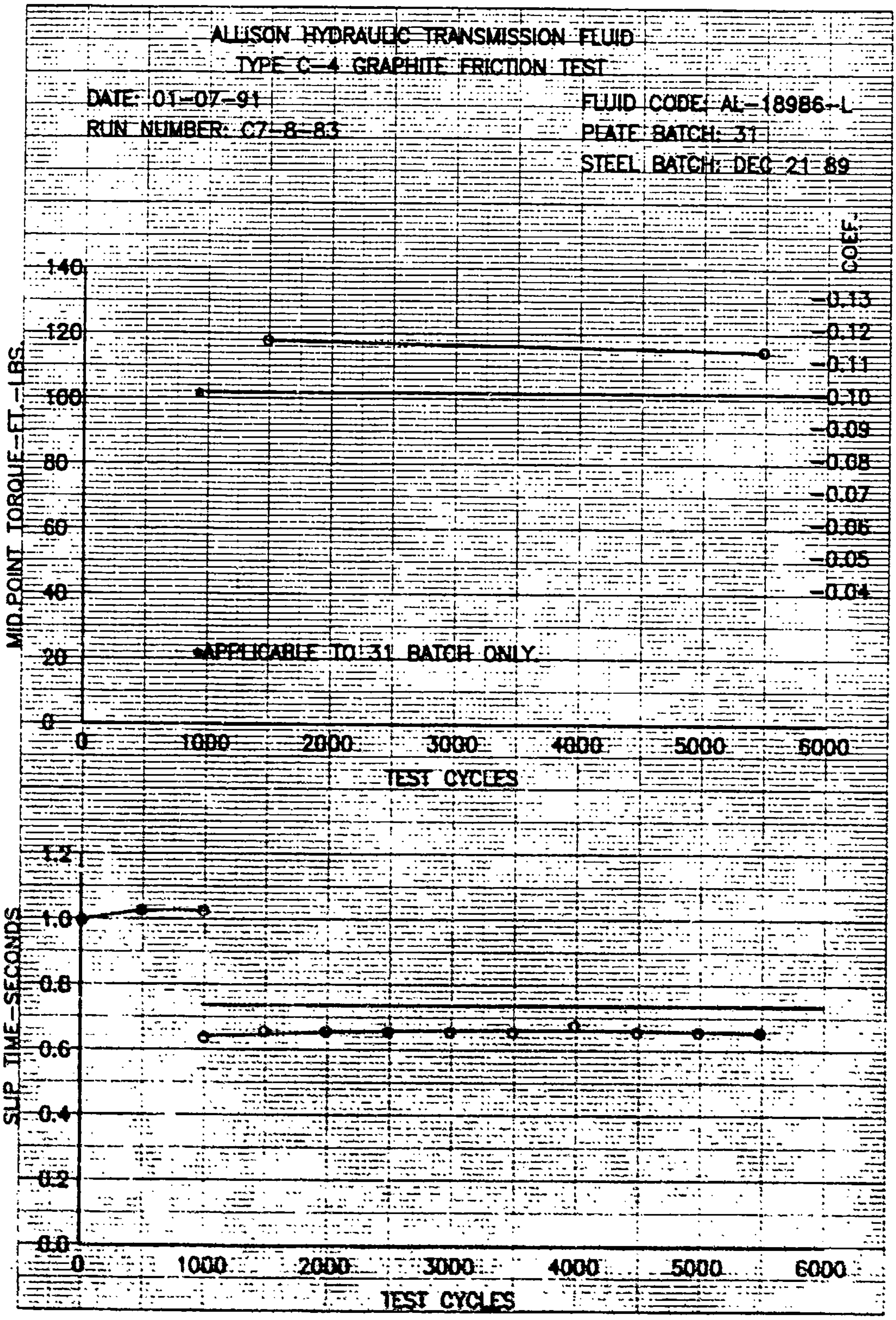
Pack No: #2?5 C-4 Graphite Lot 31 Dec 21 '89 Steel's

Candidate Fluid I.D.: AL-18986-L

Operator Name: Mark Holmes

Friction Plates		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
2 Clockwise	Top	0.0865	0.0831	0.0034	0.0857	0.0834	0.0023
	120	0.0868	0.0829	0.0039	0.0858	0.0831	0.0027
	240	0.0866	0.0836	0.0030	0.0859	0.0834	0.0025
			Average	**0.0034**		**Average**	**0.0025**

Steel Separators		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
1 Clockwise	Top	0.0668	0.0667	0.0001	0.0668	0.0666	0.0002
	120	0.0665	0.0662	0.0003	0.0665	0.0663	0.0002
	240	0.0680	0.0669	0.0001	0.0665	0.0664	0.0001
			Average	**0.0002**		**Average**	**0.0002**
3 Clockwise	Top	0.0675	0.0675	0.0000	0.0676	0.0674	0.0002
	120	0.0678	0.0675	0.0003	0.0677	0.0674	0.0003
	240	0.0675	0.0674	0.0001	0.0674	0.0674	0.0000
			Average	**0.0001**		**Average**	**0.0002**



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST
DATE: 01-07-91
RUN NUMBER: C7-8-83
FLUID CODE: AL-18986-L
PLATE BATCH: 31
STEEL BATCH: DEC 21 89
MID POINT TORQUE-FT.-LBS.
COEF.
*APPLICABLE TO 31 BATCH ONLY.
TEST CYCLES
SLIP TIME-SECONDS
TEST CYCLES

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-19528-L
Run Number: C7-1-87

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

January 11, 1991

C-4 HEAVY-DUTY TRANSMISSION FLUID SPECIFICATION	ALLISON TRANSMISSION DIVISION GENERAL MOTORS

VIII. GRAPHITE CLUTCH FRICTION TEST REPORT

TESTING LABORATORY:	SwRI	SPONSOR FLUID CODE:	AL-19528-L
TEST NUMBER:	C7-1-87	LAB FLUID CODE:	---

FRICTION PLATE BATCH No:	31
STEEL PLATE BATCH No:	Dec 21 89

CHEMICAL ANALYSIS

	METHOD	RESULTS	UNITS	ATD USE ONLY MAX	ATD USE ONLY MIN
SILICON	ICP	---	ppm		
BARIUM	ICP	---	ppm		
BORON	ICP	---	ppm		
CALCIUM	ICP	---	ppm		
MAGNESIUM	ICP	---	ppm		
PHOSPHORUS	ICP	---	ppm		
SODIUM	ICP	---	ppm		
ZINC	ICP	---	ppm		
* VIS @ 40 C	ASTM D445	---/37.23	cst		
* VIS @ 100 C	ASTM D445	---/7.34	cst		
* IRON	ICP	---/18	ppm		

* START/END

FRICTION CHARACTERISTICS

	LIMITS		RESULTS			PASS	FAIL
	5,500 N	% CHANGE	1,500 N	5,500 N	% CHANGE		
SLIP TIME (SECONDS)	0.74 max	---	0.71	0.76	7.04		X
0.2-SECONDS DYNAMIC COEFFICIENT	---	---	0.097	0.083	14.43		
MID-POINT FRICTION COEFFICIENT	0.096 min	---	0.098	0.094	4.08		X
STATIC FRICTION COEFFICIENT	---	---	0.145	0.139	4.14		
LOW SPEED PEAK FRICTION COEFF.	---	---	0.145	0.139	4.14		
.25 SECOND LOW SPEED COEFF.	---	---	0.145	0.139	4.14		

CLUTCH WEAR DATA

	MAXIMUM WEAR		AVERAGE WEAR		PASS	FAIL
	LIMITS	RESULTS	LIMITS	RESULTS		
STEEL PLATES (2)	---	0.0034	---	0.0003		
CLUTCH PLATE (1)	---	0.0022	---	0.0020		
PACK CLEARANCE	BEFORE	0.015	AFTER	0.020		

REFERENCE TESTS

TEST NUMBER	TEST DATE	TEST FLUID
C7-0-29	06-21-90	DOA-PASS-L
C7-0-70	12-04-90	DOA-PASS-L
C7-0-75	12-18-90	DOA-PASS-L
C7-0-86	01-10-91	DOA-PASS-L

NAME: Raymond D. Townsend, Jr.

SIGNATURE: [signature]

TITLE: Group Leader

DATE: January 11, 1991

C-4

CLUTCH PACK IDENTIFICATION AND INSPECTION FOR FRICTION MODIFIED FLUIDS

Date: January 11, 1991

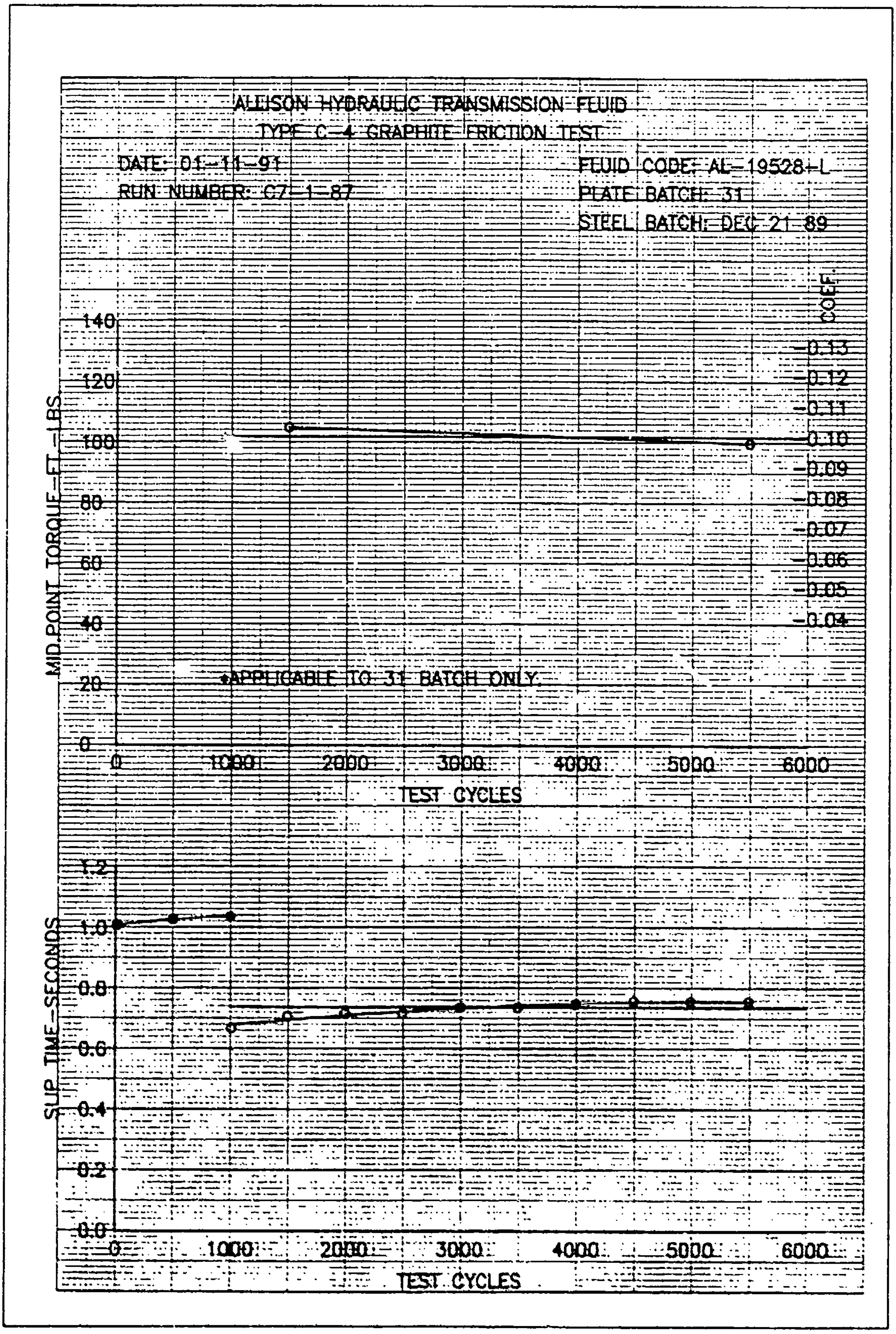
Pack No: #289 C-4 Graphite Lot 31
Dec 21 '89 Steel's

Candidate Fluid I.D.: AL-19528-L

Operator Name: Mark Holmes

Friction Plates		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
	Top	0.0867	0.0847	0.0020	0.0863	0.0845	0.0018
2	120	0.0868	0.0847	0.0021	0.0867	0.0845	0.0022
Clockwise	240	0.0868	0.0846	0.0022	0.0861	0.0845	0.0016
			Average	**0.0021**		**Average**	**0.0019**

Steel Separators		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
	Top	0.0683	0.0679	0.0004	0.0679	0.0678	0.0001
1	120	0.0681	0.0681	0.0000	0.0684	0.0680	0.0004
Clockwise	240	0.0680	0.0676	0.0004	0.0681	0.0679	0.0002
			Average	**0.0003**		**Average**	**0.0002**
	Top	0.0688	0.0684	0.0004	0.0685	0.0682	0.0003
3	120	0.0682	0.0680	0.0002	0.0682	0.0680	0.0002
Clockwise	240	0.0682	0.0681	0.0001	0.0685	0.0680	0.0005
			Average	**0.0002**		**Average**	**0.0003**


ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST
DATE: 01-11-91
RUN NUMBER: C7-1-87
FLUID CODE: AL-19528-L
PLATE BATCH: 31
STEEL BATCH: DEC 21 89
COEF.
MID POINT TORQUE—FT.—LBS.
*APPLICABLE TO 31 BATCH ONLY.
TEST CYCLES
SLIP TIME—SECONDS
TEST CYCLES

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

BELVOIR FUELS & LUBRICANTS RESEARCH FACILITY

AL-18930-L
Run Number: C7-2-88

Raymond D. Townsend, Jr.
Group Leader
Automatic Transmission Fluids
Section

January 12, 1991

VIII. GRAPHITE CLUTCH FRICTION TEST REPORT

TESTING LABORATORY:	SwRI	SPONSOR FLUID CODE:	AL-18930-L
TEST NUMBER:	C7-2-88	LAB FLUID CODE:	---

FRICTION PLATE BATCH No:	31
STEEL PLATE BATCH No:	Dec 21 89

CHEMICAL ANALYSIS

	METHOD	RESULTS	UNITS	ATD USE ONLY MAX	ATD USE ONLY MIN
SILICON	ICP	---	ppm		
BARIUM	ICP	---	ppm		
BORON	ICP	---	ppm		
CALCIUM	ICP	---	ppm		
MAGNESIUM	ICP	---	ppm		
PHOSPHORUS	ICP	---	ppm		
SODIUM	ICP	---	ppm		
ZINC	ICP	---	ppm		
* VIS @ 40 C	ASTM D445	---/44.61	cst		
* VIS @ 100 C	ASTM D445	---/8.45	cst		
* IRON	ICP	---/103	ppm		
* START/END					

FRICTION CHARACTERISTICS

	LIMITS 5,500 N	LIMITS % CHANGE	RESULTS 1,500 N	RESULTS 5,500 N	RESULTS % CHANGE	PASS	FAIL
SLIP TIME (SECONDS)	0.74 max	---	0.72	0.72	0.00	x	
0.2-SECONDS DYNAMIC COEFFICIENT	---	---	0.097	0.093	4.12		
MID-POINT FRICTION COEFFICIENT	0.096 min	---	0.100	0.100	0.000	x	
STATIC FRICTION COEFFICIENT	---	---	0.133	0.131	0.150		
LOW SPEED PEAK FRICTION COEFF.	---	---	0.126	0.126	0.000		
.25 SECOND LOW SPEED COEFF.	---	---	0.126	0.126	0.000		

CLUTCH WEAR DATA

	MAXIMUM WEAR LIMITS	MAXIMUM WEAR RESULTS	AVERAGE WEAR LIMITS	AVERAGE WEAR RESULTS	PASS	FAIL
STEEL PLATES (2)	---	0.0007	---	0.0004		
CLUTCH PLATE (1)	---	0.0045	---	0.0040		
PACK CLEARANCE	BEFORE	0.017	AFTER	0.020		

REFERENCE TESTS

TEST NUMBER	TEST DATE	TEST FLUID
C7-0-29	06-21-90	DCA-PASS-L
C7-0-70	12-04-90	DCA-PASS-L
C7-0-75	12-18-90	DCA-PASS-L
C7-0-86	01-10-91	DCA-PASS-L

NAME: Raymond D. Townsend, Jr.

SIGNATURE: Raymond D. Townsend Jr.

TITLE: Group Leader

DATE: January 12, 1991

CLUTCH PACK IDENTIFICATION AND INSPECTION FOR FRICTION MODIFIED FLUIDS

Date: January 12, 1991

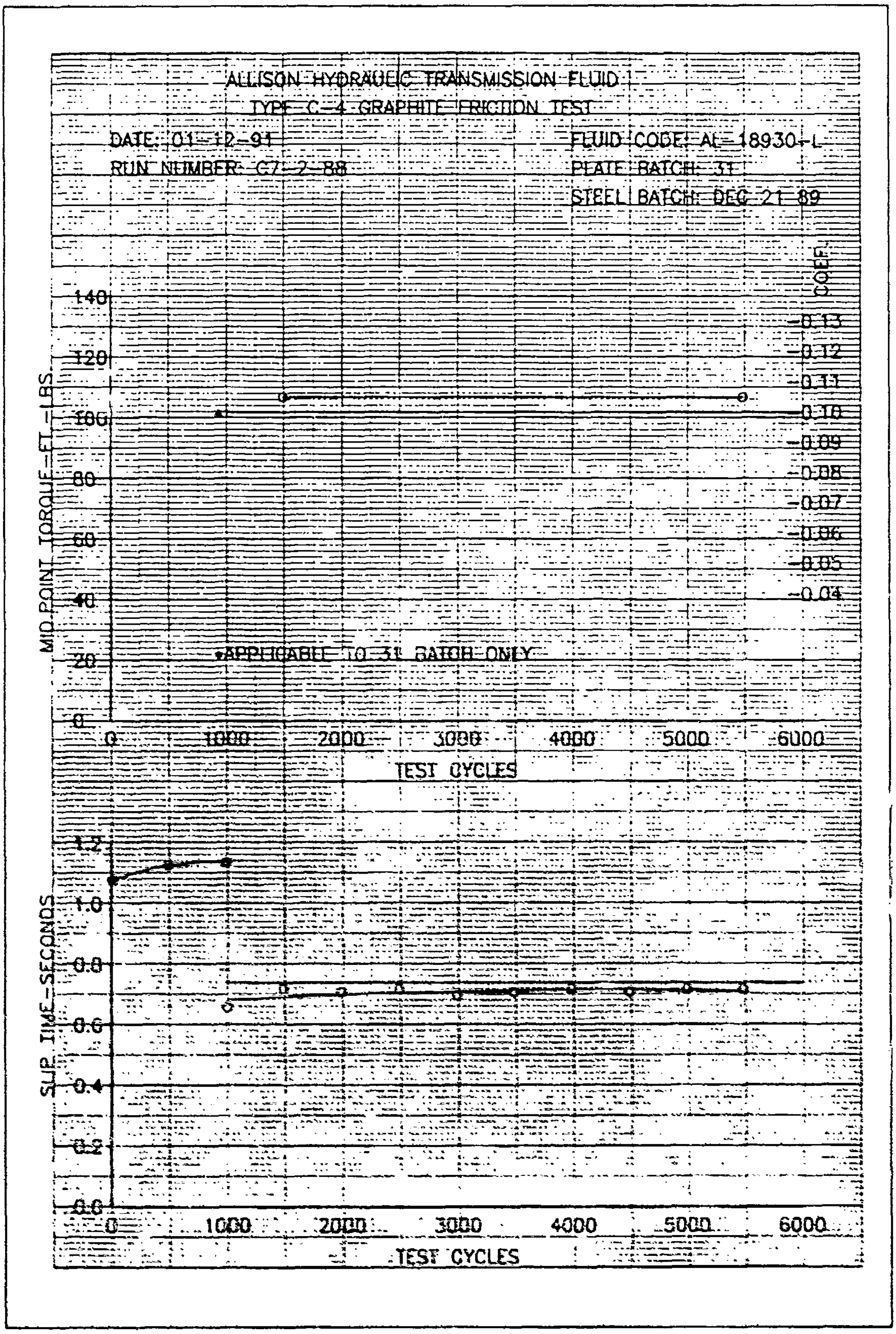
Pack No: #290 C-4 Graphite Lot 31 Dec 21 '89 Steel's

Candidate Fluid I.D.: AL-18930-L

Operator Name: Mark Holmes

Friction Plates		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
	Top	0.0881	0.0836	0.0045	0.0871	0.0832	0.0039
2	120	0.0877	0.0835	0.0042	0.0873	0.0833	0.0040
Clockwise	240	0.0879	0.0836	0.0043	0.0869	0.0836	0.0033
			Average	**0.0043**		**Average**	**0.0037**

Steel Separators		Thickness					
		Near Inner Diameter			Near Outer Diameter		
Plate No.	Location	Before	After	Change	Before	After	Change
	Top	0.0678	0.0675	0.0003	0.0679	0.0675	0.0004
1	120	0.0683	0.0676	0.0007	0.0679	0.0676	0.0003
Clockwise	240	0.0676	0.0672	0.0004	0.0678	0.0676	0.0002
			Average	**0.0005**		**Average**	**0.0003**
	Top	0.0681	0.0675	0.0006	0.0679	0.0675	0.0004
3	120	0.0676	0.0673	0.0003	0.0679	0.0673	0.0006
Clockwise	240	0.0678	0.0674	0.0004	0.0676	0.0675	0.0001
			Average	**0.0004**		**Average**	**0.0004**


ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST
DATE: 01-12-91
RUN NUMBER: C7-2-88
FLUID CODE: AL-18930-L
PLATE BATCH: 31
STEEL BATCH: DEC 21 89
MID POINT TORQUE-FT.-LBS.
COEF.
*APPLICABLE TO 31 BATCH ONLY
TEST CYCLES
SLIP TIME-SECONDS
TEST CYCLES

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Department of the Army

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WATERVLIET NY 12189

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(DR REICHENBACH) 1
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WARREN MI 48397-5000

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PM BFVS, ATTN: SFAE-ASM-BV 1
PM 113 FOV, ATTN: SFAE-ASM-AFAS 1
PM M9 ACE, ATTN: SFAE-ASM-FARVA 1
PM IMP REC VEH, ATTN: SFAE-ASM-CMV 1
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ATTN: ATSP-CD-MS 1
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FORT RUCKER AL 36362

CDR
US ARMY ENGINEER SCHOOL
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US ARMY SAFETY CENTER
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WASHINGTON DC 20315

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ABERDEEN PROVING GROUND MD 21005

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US ARMY WESTERN COMMAND
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FORT SCHAFTER HI 96858-5100

CINC
US SPECIAL OPERATIONS COMMAND
ATTN: SOJ4-P 1
MACDILL AFB FL 33608

CDR
US CENTRAL COMMAND
ATTN: CINCCEN/CC J4-L 1
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HQ, EUROPEAN COMMAND
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VAIHINGEN, GE
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ALEXANDRIA VA 22322

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ALEXANDRIA VA 22304-6180

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
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WASHINGTON DC 20380

OFFICE OF THE CNO
ATTN: OP-7[illegible]D 1
DEPT OF NAVY
WASHINGTON DC 20350

JOINT OIL ANALYSIS PROGRAM -
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BLDG 780
NAVAL AIR STATION
PENSACOLA FL 32508-5300

CDR
NAVAL AIR SYSTEMS COMMAND
ATTN: CODE 53632F (MR MEARNS) 1
WASHINGTON DC 20361-5360

CDR
NAVAL RESEARCH LABORATORY
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US MARINE CORP LIAISON
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(TACOM)
WARREN MI 48397-5000

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STATION
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PHILADELPHIA PA 19112-5083

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USMC RD&A COMMAND
ATTN: PM GND WEAPONS (CB6T),
LTC VARELLA 1
SSEA (LTC PHILLIPS) 1
QUANTICO VA 22134-5080

COMMANDING GENERAL
USMC RD&A CMD
ATTN: CODE SSCMT 1
WASHINGTON DC 20380-0001

H&S BATTALION
ATTN: MCCDE (CODE WF12E1) 1
WARFIGHTING CENTER
QUANTICO VA 22134-5010

Department of the Air Force

HQ, US AIR FORCE
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WASHINGTON DC 20330

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SAALC/LDPE (MR ELLIOT) 1
KELLY AIR FORCE BASE TX 78241

CDR
WARNER ROBINS AIR LOGISTIC CTR
ATTN: WRALC/LVR-1 (MR PERAZZOLA) 1
ROBINS AIR FORCE BASE GA 31098

615 SMSQ/LGTV (MMEP) 1
BLDG 100 ROOM 234
EGLIN AIR FORCE BASE FL 32542-5000

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WRIGHT-PATTERSON AFB OH 45433-6563

CDR
DET 29
ATTN: SA-ALC/SFM 1
CAMERON STATION
ALEXANDRIA VA 22304-6179

CDR
USAF 3902 TRANSPORTATION SQUADRON
ATTN: LGTVP (MR VAUGHN) 1
OFFUTT AIR FORCE BASE NE 68113

Other Organizations

NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION 1
LEWIS RESEARCH CENTER
CLEVELAND OH 44135

DEPT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
AWS-110 1
800 INDEPENDENCE AVE, SW
WASHINGTON DC 20590

DEPARTMENT OF ENERGY
CE-151, ATTN: MR JOHN RUSSELL 1
1000 INDEPENDENCE AVE, SW
WASHINGTON DC 20585

ENVIRONMENTAL PROTECTION AGENCY
AIR POLLUTION CONTROL 1
2565 PLYMOUTH ROAD
ANN ARBOR MI 48105